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# The effect of hardwood component on grapple skidder and stroke delimber idle time and productivity – An agent based model

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ABSTRACT

The forest industry is a capital intensive business and therefore high efficiency in management and forest operations is a must. Maine has millions of acres of forest stands with tree diameters smaller than 30 cm. The harvest productivity in such stands is low compared to stands with larger diameter trees. A recent harvest productivity study in Maine identified operational constraints for whole tree harvest systems, but efforts to improve active operations would be expensive and time consuming. A common practice to reduce costs and time consumption is to develop simulation models and implement new ideas within them. We developed a production efficiency model that leverages an agent-based modeling approach. The model is based on the interaction of two common forest machines (grapple skidder and stroke delimber) and incorporates empirical cycle time estimates from research in Maine. Three scenarios have been developed to investigate baseline conditions, and two GPS and GIS aided communication improvements. The goal of this paper is to document a new agent based model and to investigate the effect of hardwood component on machine idle time and productivity. Results showed that system productivity was affected by skidding distance, bunch spacing, and removal intensity. An increase in hardwood component led to a decrease in stroke delimber idle time but did not affect grapple skidder idle time. Further, hardwood component did not affect system productivity, and none of the three single-skidder scenarios tested performed any better than another. We validated the model by conducting a sensitivity analysis to confirm previous research results. The modeled waiting times are well within the range of observed values and therefore suggest that this model is accurate and well calibrated. Our conclusions are that when operating under average harvesting conditions there is no loss in productivity due to a change in hardwood component and that a stroke delimber idle time of 40% or more is unavoidable unless the stroke delimber can work independently. Future applications of this model may target specific production forestry conditions.



## 1. Introduction

Due in part to regenerating clearcuts from the spruce budworm era in the 1970s and 1980s, forest operations managers in Maine must manage an increasing percentage of stands that consist of small-diameter stems (dbh < 30 cm). Approximately 11 million acres of forest land in Maine contain or are dominated by trees smaller than 30 cm in dbh (McCaskill et al., 2011). Forest operations are an important part of the forest industry but are also very capital intensive (Purfürst, 2010). Due to the high capital investment in harvesting equipment, and the cost of running the machines, it is important to know machine productivity to fully utilize the individual machines. Effective management of forest operations therefore requires accurate estimates of harvest costs and productivity, although the monitoring of these variables may be difficult (Holzleitner et al., 2011; Wang et al., 2004). The two dominant and fully mechanized harvesting systems in Maine are whole-tree (feller-buncher, grapple skidder, stroke delimber) and cut-to-length (harvester, forwarder) (Leon and Benjamin, 2013). As the names suggest, whole-tree harvesting operations severe the tree from the stump and then transport it to the roadside including all branches as a whole tree, cut-to-length harvesting operations on the other side, severe trees from the stump and then cut off the branches and crosscut the bole into specific length logs, which are then transported to the roadside. These harvesting systems are generally very productive when operating in large diameter tree stands but have a reduced productivity when operating in small diameter tree stands (Hiesl and Benjamin, 2013a). With high investments in equipment it is therefore crucial to achieve high

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machine productivities to keep the unit cost at a low level. To increase the productivity of individual machines and the harvesting system it is therefore necessary to improve or change existing harvesting processes.

The primary goal of any logging contractor is to generate revenue to pay for the equipment and to create income. Maximizing machine utilization is one way to reach this goal and is described as the most important objective of a logging contractor (Bolding, 2008). In order to maximize the utilization of a machine it is important to know where bottlenecks are. Several methods are available to identify these bottlenecks. Time studies are a common tool to evaluate harvesting operations and identify bottlenecks, however, they can be rather time consuming (Bazghandi, 2012; Bolding, 2008; Bradley et al., 1976). Another accepted method to analyze the productivity and impact of a harvesting system are simulation models (Baumgras et al., 1993; Bradley et al., 1976; Garner, 1978; Goulet et al., 1979; Li et al., 2006; Polley, 1987; Wang and LeDoux, 2003). Also often used are individual tree growth simulators such as Forest Vegetation Simulator (FVS) (Dixon, 2002), and regional volume and taper equations (e.g. Li et al., 2012; Weiskittel and Li, 2012). Individual tree growth models are especially useful in combination with cycle time equations for harvesting equipment that are based on individual trees (e.g. Hiesl and Benjamin, 2015, 2013a; Spinelli et al., 2010; Adebayo et al., 2007). Simulation models have several benefits compared to time and motion studies, such as fast execution of models and the possibility of changing system settings without changing the real system (Bazghandi, 2012; Bradley et al., 1976; Polley, 1987). The use of simulation models is not new to the forestry community as simulation models have been available since the 1960s (Goulet et al., 1979; Polley, 1987).

Before 2013, no harvesting productivity studies were conducted in Maine and therefore no up-to-date productivity information for harvesting systems operating in Maine's forests was available to conduct such computer simulations (Hiesl and Benjamin, 2013a). In 2012 and 2013, researchers at the University of Maine collected cycle time and productivity data for five pieces of equipment (feller-buncher, harvester, grapple skidder, forwarder, stroke delimber) commonly used in Maine, and developed cycle time and productivity equations (Hiesl and Benjamin, 2013b, 2013c, 2015; Hiesl, 2013). With these newly developed equations it is now possible to simulate the time consumption and productivity of different harvesting systems in a variety of site and stand conditions. The logical extension of the time and motion study conducted by Hiesl (2013) therefore is to use this data to identify bottlenecks and to develop simulations with the new productivity data to test various scenarios of possible improvements in forest operations. Observations during the field study showed that harvesting operations consist of a large amount of non-productive waiting time.

Harvesting equipment used in whole-tree and cut-to-length harvesting systems mostly operate independent from each other. The interactions between stroke delimbers (Fig. 1) and grapple skidders (Fig. 2) are an exception to this. The grapple skidder delivers wood to be processed by the stroke delimber and often has to wait for the stroke delimber to finish processing wood from the previous load. Polley (1987) found that waiting times between 20% and 40% have to be expected due to this dependency. The recommendation from Polley's research was to avoid such technological coupling of new equipment. Today, however, these two machines are still very much dependent on each other. Huth et al. (2004) commented that the existence of harvesting systems for many years and decades does not necessarily mean that their use is sustainable. Today with decreasing profit margins, large percentages of idle time due to technological coupling of grapple skidder and stroke delimber cannot be tolerated.

**Fig. 1.** A stroke delimber generally processes one tree at a time by cutting off branches and the top above a specific merchantable diameter.

**Fig. 2.** A grapple skidder generally transports several trees in a bunch from the forest to the roadside where the whole trees get processed by a stroke delimber.

Whole-tree harvesting systems are the most important harvesting systems in Maine in terms of volume cut (Leon and Benjamin, 2013). Unpublished data of Hiesl (2013) showed that there is a waiting time ranging from 0% to 57% present when a grapple skidder and stroke delimber work together at a variety of commonly encountered site and stand conditions in Maine (Fig. 3). With the feller-buncher working independently we can therefore identify the interaction of the grapple skidder and the stroke delimber as the bottleneck in most whole-tree harvesting systems. Research has further shown that the processing time of stroke delimbers is negatively impacted when processing hardwoods (Hiesl, 2013). As with harvesters (Glöde, 1999), the generally larger branch size increases the processing time for stroke delimbers as well. Maine's forest land consists of over 50% of hardwood forest types (McCaskill et al., 2011), and land managers and logging contractors alike have to deal with the negative impact of hardwoods on harvesting productivity. Research in Maine has shown that stroke delimber productivity is lower for processing hardwoods than it is for processing softwoods (Hiesl and Benjamin, 2013c; Hiesl, 2013). This can be attributed to the increased processing time due to large branches that cannot easily be broken off. This highlights the importance to understand the impact of an increasing hardwood component on stroke delimber and grapple skidder idle time.

Presently, there are three computer simulation methods available for modeling different abstraction levels, such as System Dynamics, Discrete Event, and Agent Based (Borshchev and